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Kinesthetic Life Cycle of Stars

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Abstract

We present a kinesthetic approach to learning about the life cycle of stars. Using a simplified two-layer model for stellar structure, learners recreate kinesthetically the birth, life, and death of low- and high-mass stars. Examples of how this activity has been used in several settings outside school time provide additional resources for extending student learning about this topic.

1. INTRODUCTION

The story of stellar evolution is powerful and dynamic. Knowing how stars live and die lends background to observations made by casual observers and professional scientists alike. Yet many presentations of these ideas in classroom and out-of-school settings do not offer students the opportunity to immerse themselves in their own cosmic origins. We present a dynamic model for stellar evolution, in which students become clumps of gas in a star-forming nebula and reenact kinesthetically the journey from nursery to death. Through a simplified two-layer model of how stars work, students will:

1. Learn about the basic stages of stellar evolution
2. Learn about the different end states of low- and high-mass stars

By kinesthetically modeling the birth, life, and death of stars, students can make concrete connections to physical processes in the universe, processes that are not explicitly revealed through photographs of stars and nebulae. Such images appear frequently in classroom and media settings, yet the most common contextual representation of how these images fit together is a diagram-like chart that traces the paths of stellar evolution. This activity should not replace such explanatory resources, but should instead provide a physical interpretation of the processes that appear on these illustrations as mere arrows. When combined with reflective discussion and extension activities, this reenactment allows students to focus their thinking about astronomical phenomena and make more sophisticated observations about objects in the universe.

Science education literature demonstrates the value of kinesthetic dramatizations in making invisible processes more accessible to students, especially in the field of biology (Ross, Tronson, & Ritchie 2008; Chinnici, Yue, & Torres 2004; Wyn & Stegnik 2000), but also in astronomy (Morrow 2000). The three-dimensional nature of stars and nebulae in the universe is not immediately apparent through simple observation of telescopic images, let alone naked-eye observation, but it is well suited to this type of physical interpretation and role-play. The processes that drive the evolution of stars, namely fusion and gravitational collapse, are inherently dramatic, and the tension between the two during a star's life and death provides compelling subject matter for such interactive storytelling.

The activity is also useful for addressing common student questions and misconceptions. Students often ask how black holes form and whether our Sun will become one. The second learning goal of this activity provides a first-level answer for both of these questions, whereas the first addresses common student confusion about the difference between stars and planets, as well as the question of whether our Sun is a star. If a discussion of nucleosynthesis is included in the activity, facilitators can begin to address the misconception that all elements in the universe were created in the Big Bang. More generally, many students assume that stars (and galaxies) emerge fully formed out of the Big Bang (Sadler, Coyle, & Dussault, 2008) This kinesthetic dramatization tells the larger story, making visible the basic forces associated with stellar evolution and illustrating the nature of change in the universe.

2. PREPARATION

2.1 Materials

The only materials necessary for this activity are the students themselves, but the experience can be enriched by the use of additional props, including:

1. Images of humans in various stages of life
2. A demonstrative poster highlighting key phases of stellar evolution
3. Astronomical images of stars and nebulae, showing different phases of stellar evolution

2.2 Setting and Safety

Facilitators should present this activity outside or in an empty room. A standard middle school classroom with furniture pushed to the side will allow appropriate maneuverability. Suggested ground rules for students include waiting for a facilitator's verbal cue before beginning any motion, and, of course, no aggressive behavior. Those with larger groups or smaller spaces may wish to run sequences in dramatic slow motion, like advancing a DVD frame by frame. The full sequence will take approximately 20–40 minutes.

2.3 Group Size

We recommend 8–12 students per stellar model, although the activity has been successful in groups of 6–24. With fewer students, the facilitator will become part of the model; with larger groups, the facilitator can serve primarily as a narrator and instruction-giver, lending a guiding hand only when students stray from the action. For groups larger than 12, we recommend splitting the students into two groups and having the groups take turns modeling and observing the life and death of one particular (high- or low-mass) star. When we piloted this activity with a group of 24, the observing group stood around the room, providing sound effects for the other group's model of the low-mass star. After the planetary nebula phase, the groups switched, and the original observers were given the challenge of recreating the model they had seen, up through the red giant phase, before receiving instructions for the supernova stage and beyond. The group that had previously modeled the low-mass star provided sound effects and recalled the action from the stages that they had already enacted to guide the high-mass star through its first few stages of life.

3. PROCEDURE

3.1 Introducing the Activity

Challenge students to put in order photographs of people in various stages of life. Encourage them to notice details of the images and justify their reasoning by identifying features and patterns in each "stage" (e.g., graying hair, smaller size during infancy). If you wish, ask them to repeat one or both levels of the challenge using photographs of stars and nebulae. Noticing details and comparing characteristics of specific images will be a reasonable task, but putting them in order from youngest to oldest will be difficult and frustrating for students, who do not think of stars as having ages, let alone a relationship to the nebulae that astronomers observe. However, the questions raised by this challenge can motivate the concept that stars, like humans, change in predictable ways as they develop, and the idea that this activity will explore the processes that affect a star's structure and appearance throughout its life.

Facilitators may also wish to provide some introductory reflection around students' ideas about stars. Asking students what they think will happen to our Sun in the future or showing them a picture of actual stars in the sky offers concrete motivation and a reference for students to think about actual objects in the universe (the constellation of Orion, which contains both a star-forming nebula and stars of various types and ages, is an excellent candidate). By providing a brief introductory overview of objects to be explored, facilitators better equip students to delve into the details of the evolutionary story.

Regardless of how the activity is introduced, it is best to explicitly tell students that they are going to create, with their bodies, a model that explains how stars live and die, and they will recreate, through their interactions with each other, live-action versions of the photographs taken by astronomers. Students represent clumps of gas and dust many times more massive than the Earth. These clumps move and change only when pushed or pulled by interaction with the surrounding clumps of gas (and dust). The kinesthetic activity explores the ongoing interplay between two such influences: gravitational force and gas pressure generated by fusion in the star's core. To get students used to the idea of impersonating these clumps of gas, show them an image of a star-forming nebula and ask them to visualize what it would be like to live or move inside that cloud. Once they have imagined the setting of their impending dramatization, they will be in a better mindset for immersing themselves in role-play.

3.2 Modeling Stages of Stellar Evolution

Five stages of stellar evolution are described (Table 1) and illustrated (Figure 1). In each stage, facilitators should provide a brief narration of the science and physical actions that are about to occur before "starting the clock." It may be instructive to show a poster that illustrates the stages of stellar evolution or to preview the images that the students will recreate at each stage. Once the action begins, students move into the appropriate formation. Facilitators may need to provide more detailed instruction or hands-on guidance to individual students. Once students have completed the action of a stage, they should stop moving while facilitators briefly summarize the process, show an image of a star in that stage of life, and begin the next segment of narration.

We recommend presenting the core activity as a facilitator-narrated sequence because the basic information necessary for students to come up with this model on their own requires significant time and research (an example of how a student-researched reenactment might work is provided in section 3.2.1). Facilitators should limit their explanations at each stage to one minute or less. Supplementary details to the core content should be explored in repeat performances of the simulation or follow-up reflection.

The Description column in Table 1 does not represent verbatim narration, but rather a summary of basic principles involved in each stage. In particular, facilitators should emphasize the interplay between the inward force of gravity that pulls the star together, and the outward force that results from fusion in the core.

Table 1. Stages of Stellar Evolution

Stage	Description	Action
Star-Forming Nebula [Gravity rules.]	A cloud of gas and dust forms many stars. A single star is created when clumps of this material (mostly hydrogen gas) are pulled together by the force of gravity.	Students, scattered randomly throughout the room, point in the direction where "the most other clumps" are and slowly make their way to that point.
Birth of the Star (Protostar) [Gravity rules. Fusion begins.]	As a region of the cloud collapses, gravity pulls the clumps of gas together. The gas in the center becomes hot enough and dense enough to begin fusion. Hydrogen atoms inside the clumps smash into each other, combining to create helium and releasing light and heat. The star begins to shine.	Students clump together, forming a large ball. Those on the outside ("envelope") continue to move toward the center. When students on the inside ("core") start bumping into each other, they face outward.

Life of the Star (Main Sequence) [Gravity and fusion in balance.]	Fusion in the core generates an outward force to balance the inward gravitational force from the outer layers.	Core students and envelope students gently push against each other, palm-to-palm, elbows bent, balancing. There should be one or two envelope students for every core student.
Red Giant [Fusion overtakes gravity.]	As the core nears the end of its fuel supply, the outer layers continue to push inward, increasing the temperature in the core. This produces a new series of fusion reactions that produce enough outward force to overpower the inward gravitational force and expand the star.	Core students fully extend their arms, pushing the envelope students backwards, expanding the star.
Death of a Low-Mass Star (Planetary Nebula with White Dwarf) [Fusion ends; gravity wins.]	As the core runs out of fuel for fusion, it emits one last push outward, ejecting the star's outer layers, which drift away into space. The core then contracts under its own gravity, forming a white dwarf.	Core students push the envelope outward then move together into a tight blob at the center. The envelope students, in a ringlike shape, drift away from the core.
Death of a High-Mass Star (Supernova, with Neutron Star or Black Hole) [Fusion ends. Gravity wins.]	The massive core continues to fuse elements and expands the star so it is even larger. Once the core runs out of fuel, it collapses to form a neutron star. The outer layers then collapse as well. As material falls toward the star's center, it bounces off the core and explodes outward through the star. This explosion is called a supernova. In the most massive stars, the collapsed core will become a black hole.	Core students extend their arms, expanding the star. Then, they stop pushing and scrunch together at the star's center. Envelope students rush inward and bounce off the packed-together students in the core, exploding outward dramatically, revealing the collapsed core.

To transition between the deaths of low- and high-mass stars, facilitators must rewind the clock to the original star-forming nebula or to the main sequence stage. Recreating all stages of the activity up to the red giant phase, from students' memory, is most effective because it highlights the parallel paths of the two stars and allows students to review and "teach back" what they have learned. While piloting this activity with a two-group setup, the same number of students represented the high-mass star as the low-mass star. It is not clear whether dividing a large group unequally or using a smaller number of students from a small group for the low-mass star adequately distinguishes the two categories of stellar mass. Similarly, the ratio of envelope students to core students (between 1:1 and 2:1) does not represent the actual distribution of mass in the different parts of the star, simply the balance between forces. However, these distinctions are better addressed during the postactivity discussion.

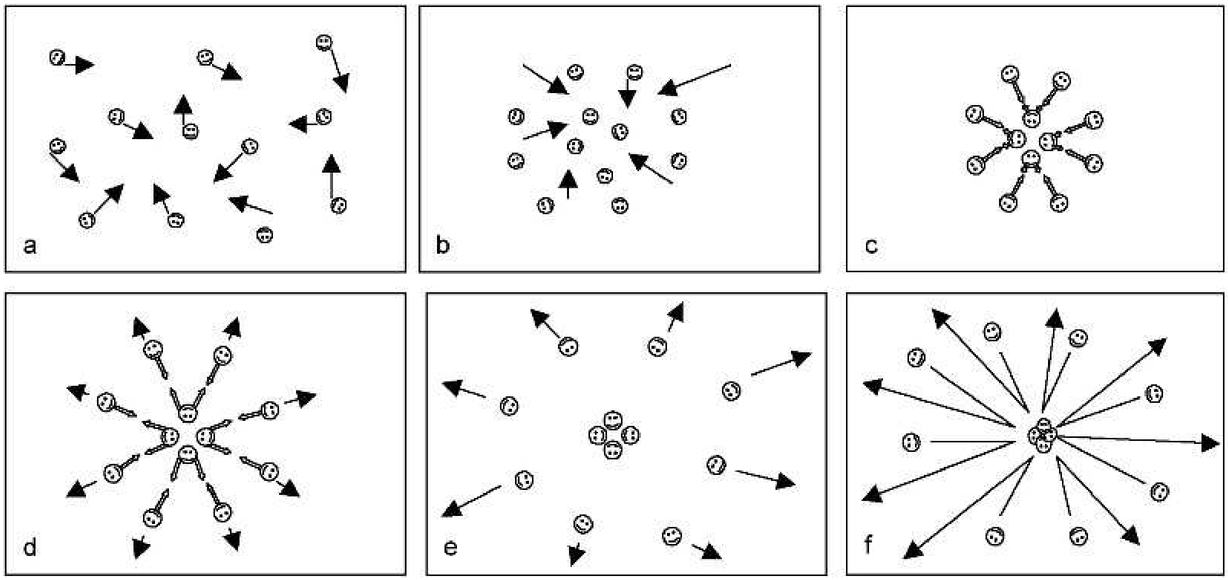

Figure 1. Student positions during each stage of the kinesthetic activity

a) Star-forming nebula (random motion)
b) Protostar (clumping, motion toward the center, core and envelope start to differentiate)
c) Main sequence (core and envelope pushing in balance)
d) Red giant (core pushing harder, motion outward)
e) Planetary nebula (core compacted, all other motion outward)
f) Supernova (core compacted, motion inward and then outward)

In pilot runs of this activity, facilitators found it helpful to pass around or project actual images of stars and nebulae during the appropriate stages. It may be difficult for students to see the connection between these images and their kinesthetic model, so it is also useful to take digital pictures of the students at each stage and compare these to the astronomical images afterward. Figure 2 illustrates an example of such a photoset.

If possible, students should teach back what they have learned by recreating the simulation on their own, with limited facilitator guidance and prompting. Repeat performances driven by student knowledge emphasize the key information and allow facilitators to step back and observe which concepts require more discussion or explanation.

Figure 2. Various stages of the kinesthetic model photographed from above and ground level. These photographs are annotated and available in higher resolution at http://www.flickr.com/photos/mkiphotos/sets/72157605963324609/. (This URL is also listed in the Resources section of this article.)

3.2.1 Student-Researched Models

The kinesthetic activity was presented to high school students who were involved in a five-week summer training session at the Massachusetts Institute of Technology (MIT) about astrophysics and data analysis techniques. Table 2 outlines the procedure used to engage these students with the ideas of stellar evolution. The experience culminated in the students creating their own kinesthetic interpretations of the various stages, videos of which have been posted to the MIT server (see the link in the Resources section).

Table 2. Student-Developed Kinesthetic Models

Stage and Timescale		**Description of Tasks**
1	~3–4 hours over 2 weeks	Small groups of students had independent responsibility for learning about the observational and physical properties of objects in several stages of the stellar lifetime: main sequence stars, white dwarfs, neutron stars, and black holes.
2	~2 hours over 2 days	By reading pieces of three separate articles (Hufnagel 1997; Chabin 2000; Kirshner 1994) that tell the story of the stellar lifetime, students were to see the connections between the objects on which they had each become experts. It was our intention that the importance of the balance between gas pressure from fusion and gravity would be clear from this reading.
3	30–60 minutes	Course instructors modeled the first stage of stellar evolution (progression from gas/dust cloud to protostar) in the same way as laid out in Table 1. Students were told that they would represent clumps of gas, and we told them how to move and what process that movement represented in the model.
4	2–3 hours	Small groups of students were then assigned different parts of the stellar evolution sequence (related to their object of expertise) and asked to develop their own representation of this stage using the structure setup (i.e., each student represents a clump of gas.) Stages were main sequence lifetime, main sequence -> red giant, red giant -> white dwarf, main sequence -> supernova -> neutron star, main sequence - > supernova -> black hole. Once they had created a diagram and narration for their stage, they were given an opportunity to "direct" the other students to rehearse their stage of the kinesthetic model.

As implied by Table 2, conducting the activity in this way requires a good deal more time and reference material than the facilitator-driven model. It should be noted that these students were chosen for the summer institute having already demonstrated a strong interest in astronomy and astrophysics. They were also familiar with the concept of kinesthetic models, having already participated in such a model demonstrating the process of fusion. Their models of stellar life cycles were dancelike in appearance and focused on the synthesis of elements and the end state at each stage. It should be noted, however, that these students were chosen for the summer institute having already demonstrated a strong interest in astronomy and astrophysics. They were also familiar with the concept of kinesthetic models, having already participated in such a model demonstrating the process of fusion.

3.3 Reflection and Discussion

The kinesthetic activity presents a simplified model of stellar evolution. Most of the in-depth content learning about these ideas will occur during follow-up reflection and extension activities. Because the simulation is one in a series of intermediate models, "partial models that are stepping stones between naïve and expert models" (Clement 2000, p. 1050), facilitators should be aware of how students internalize the concepts presented by the model. Students bring with them a variety of naïve notions about physical forces in the universe (Driver et al. 1993), which kinesthetic models often make apparent. With more time and older audiences, facilitators could expand the activity to include more details about the processes involved in stellar evolution. All audiences will benefit from a discussion about the strengths and weaknesses of the kinesthetic model. This section presents such modifications and supplementary discussion topics not included in the basic model described earlier.

3.3.1 The Nature of Models

Increasing numbers of education researchers are recognizing the importance of models in science education and the need for a theory of model-based teaching and learning (Gobert & Buckley 2000). Facilitators should use the kinesthetic activity as an opportunity to discuss the nature of models with their students, calling attention to the fact that a single model cannot represent all the aspects of a particular process or idea. Students should consider the following questions: What important aspects of the stellar lifetime does this model represent well? What does it represent poorly? What does it leave out or not represent at all? Several themes may emerge:

Three-dimensional structure in the universe: The kinesthetic model is essentially two-dimensional, which is why it is particularly useful for interpreting astronomical images, which are also two-dimensional. Further discussion and interaction will help students visualize these processes in three dimensions. For example, a discussion of the outward motion in either the planetary nebulae or supernovae stage could easily motivate the idea of an expansion in three dimensions. One could also ask students to examine an astronomical image and predict what an object would look like from the side.

Comparison to astronomical images: After completing this activity, many students become more attuned to notice specific detail in astronomical images; they become personally invested in what they are observing, with telescopes or even images in the news, on the Web, or in books. For example, by comparing the relatively gentle motion in their planetary nebula model to the violent dramatics of the supernova, students can make sense of the visual differences between the two resultant nebulae images (i.e., smooth and symmetrical vs. jagged and uneven).

Relative size and scale: As with many astronomical models, a range of several orders of magnitude is hard to represent. Students could develop a scale model of the different sizes of the objects involved. This could be as simple as the instructor presenting a range of objects with different sizes and having students choose pairs to represent what they feel is the size difference between different parts or stages of the model.

Relative time in each stage: A star is in the main sequence phase for 90% of its lifetime, but this is hard to represent in the model. Students could create a physical scaled timeline that represents the relative length of time spent in each phase.

Astronomical time scale: After completing this activity, students may think that astronomers have directly observed individual stars going through an entire life cycle. A good analogy for confronting this misconception is to ask students how a visitor to Earth might develop a model of how humans live and die based on a one-day visit to the planet. The visitor would need to observe many different people in many different stages of life and piece those observations together to develop the full story.

Relative masses of stars: With a limited number of students representing the stars, it is difficult to distinguish between the actual sizes of low- and high-mass stars. Students may come away from this model with the idea that a single cloud forms either a low- or high-mass star. The idea that a single star-forming nebula forms many stars of varying masses at different rates is an important distinction to make. This conversation can be aided by astronomical images or illustrations that show protostars in the process of being born.

3.3.2 Stellar Structure and Composition

The simplified two-layer model glosses over many details about stellar structure and hydrostatic equilibrium that are not necessary for understanding the basic mechanics of stellar evolution. Students may come to think that stars have distinct layers, similar to the diagrams of Earth’s core, mantle, crust, and so on, that they have seen in textbooks. The pressure balance in a real star, of course, is continuous. Using flashlights or cards to represent the generation of light or fusion of elements can help to distinguish where each process is happening, although it may also introduce new confusion or complications about how stars work. It is not necessary to address all these issues with students, especially those younger than college level, but the following modifications are presented for those facilitators who wish to explore astronomical processes in more depth and relate them to the origin of chemical elements on Earth.

Nucleosynthesis: Each clump of gas can be labeled with one of three colored signs worn around the student’s neck that indicates its composition: hydrogen (front) and helium (back); carbon/oxygen (front) and heavy elements up to iron (back); and elements heavier than iron (both sides). When an area of the star undergoes fusion, the students in that area flip over or swap out their signs to represent the change in composition. Students could also be given flashlights worn around the neck to turn on when fusion is happening in their represented clump. In this way, clarifications about where fusion happens and what it produces can be made clear. For instance, clouds start as mostly hydrogen, but during the main sequence, flashlights should be on in the core (not envelope); those students can switch their signs to helium and then turn off their flashlights. When all hydrogen is used up in the core, this signals the start of the next phase: expansion to a red giant. Similarly, red giants fuse helium into carbon and oxygen, which are left behind as the major components of a white dwarf. Only in the most massive stars will heavier elements be produced.

Enrichment of the interstellar medium: This discussion is possible if the described nucleosynthesis labels are used. At the end of one cycle of the stellar lifetime, the nebula that forms from the supernova explosion should now include some heavier elements, as well as hydrogen. These elements are then incorporated in the next generation (cycle) of star formation. Facilitators may wish to restart the model, recalling the star-formation/cloud collapse phase, to illustrate the cyclical nature of stellar evolution. If desired, the "second generation" model could also incorporate planets, made of elements heavier than hydrogen and helium, that orbit the new star. Introducing planets, however, may lead to additional misconceptions about size and scale. For the sake of simplicity, we have omitted the enrichment of the interstellar medium that occurs throughout a star’s life due to such phenomena as stellar winds.

3.4 Extending Student Learning

Kinesthetic experiences provide a highly dynamic way of engaging learners with science concepts. Abusson et al. (1997) found that "simulation-role-play may allow students to demonstrate their understanding, explore their views and develop deeper understanding of phenomena" (p. 565). McSharry and Jones (2000) asserted that "if done correctly, role-play is an extremely enjoyable experience both for the children and the teacher, and has a great potential for making science interesting for the disaffected or disinterested child, as well as the interested" (p. 80). Following such a simulation with hands-on activities allows students to further explore the subject matter and teach back what they have learned. This section describes three extension activities that motivate students' further questions and research and allow facilitators to assess and evaluate student learning as a result of this activity. By combining the kinesthetic experience with one or more of these extension activities, students will make concrete connections between the simulation and specific astronomy content.

3.4.1 Card-Sorting and Matching

Print out several astronomical images of stars and nebulae from the following four categories: Star-Forming Nebulae, Main Sequence Stars, Planetary Nebulae, and Supernova Remnants (see Figure 3). Ask the students to sort them into the appropriate category or place them on a poster that illustrates the life cycle of stars. Students should be sure to justify their answers. This is a good activity to do in small groups. Comparing answers among groups can lead to a rich discussion about what defines a star and the roles that nebulae play in stellar evolution.

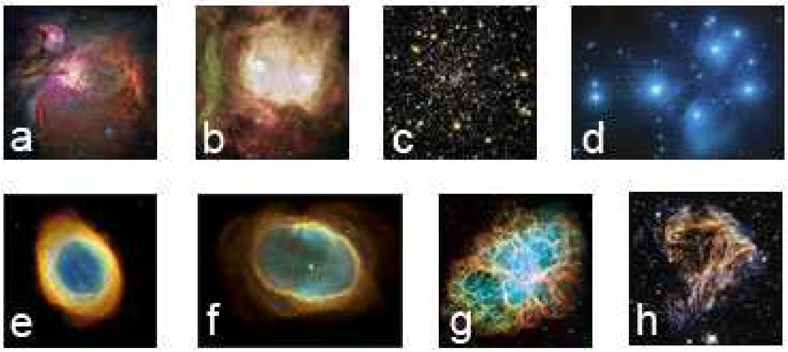

Figure 3. Representative images that have been used in previous programs

a) Orion Nebula, M42. *Credit:* NASA, ESA, M. Robberto (STScI/ESA) and the Hubble Space Telescope Orion Treasury Project Team. (Star Forming Nebula)
b) Ghost Head Nebula NGC 2080. *Credit:* NASA, ESA & M. Heydari-Malayeri (Observatoire de Paris, France). (Star Forming Nebula)
c) Star Cluster NGC 6597. *Credit:* NASA and the Hubble Heritage Team. (Stars)
d) Pleiades Star Cluster, M45. *Credit:* NASA, ESA and AURA/Caltech. (Stars)
e) Ring Nebula, M57. *Credit:* The Hubble Heritage Team. (Planetary Nebula)
f) Southern Ring Nebula, NGC 3132. *Credit:* The Hubble Heritage Team. (Planetary Nebula)
g) Crab Nebula, M1. *Credit:* NASA, ESA, J. Hester and A. Noll (ASU). (Supernova Remnant)
h) LMC N49. *Credit:* NASA and the Hubble Heritage Team. (Supernova Remnant)

This activity provides both structure and sense-making opportunities for students. It also provides a bookend to the introductory challenge described in section 3.1. By emphasizing the distinct categories of stellar evolution and/or relating them to a diagram that ties them together, students develop a mental model that is based on their own experience. The facilitator can use this activity to assess not only the content knowledge of students but also their critical thinking skills in making sense of the different images.

3.4.2 Creative Interpretation

After acting out the stages of stellar evolution and seeing astronomical photographs of stars and nebulae, students can create three-dimensional sculptures of the different types of objects (see Figure 4). Students should think about what is really going on at each stage and imagine what it would be like to be in space in or around each object. They should then share their final creations through oral presentations or written captions.

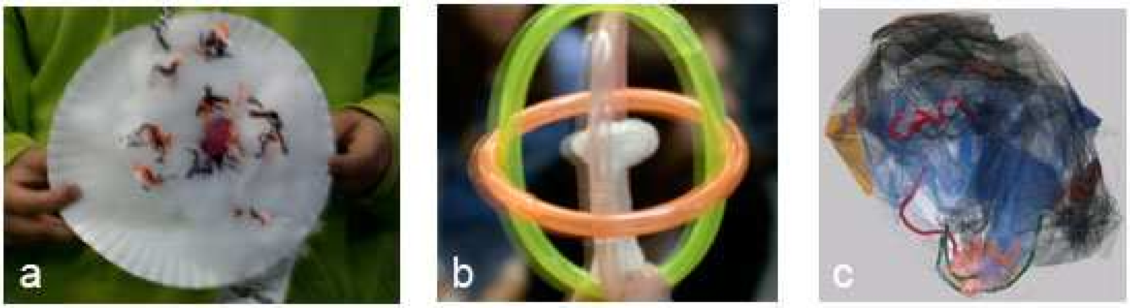

Figure 4. Models created by students after their kinesthetic experience during after-school programs or weekend workshops

1. Star-forming nebula: Cloud with ribbons of dust and condensed material at the center
2. White dwarf: White ball with rings or shells of gas surrounding it
3. Supernova remnant: A cloud with strings of shredded star and streaks of hot gas

Like the card-sorting activity, this hands-on exploration makes visible students' thoughts about their experience and allows facilitators to assess what sense students are making of the ideas presented. Logistically speaking, this activity is best done using specific astronomical images as inspiration. Students should identify an image that appeals to them and then imagine what it would look and feel like in three dimensions. They may wish to pick a favorite object (or type of object) and research it further in books or on the Web. If desired, facilitators can preassign students to model a particular stage of stellar evolution or provide a selection of categories or images from which students can choose.

By engaging students' creativity and asking leading questions about appearance, composition, texture, motion, and so on, of their chosen objects, as well as their experience as part of the kinesthetic intermediate model, facilitators can guide students to a more sophisticated model of astronomical objects and their three-dimensional nature. Facilitators may wish to assess students' creations using a qualitative rubric (Gobert, Snyder, & Houghton 2002) or scoring system (Gobert et al. 2002). With younger students, facilitators should model this activity by creating a sample sculpture and pointing out the features that relate to specific aspects of the inspiration photograph.

We also recommend motivating this activity through the creation of a museum-style exhibit to be developed by the whole group for friends and/or family in a classroom "gallery" or a public space such as a school or community library. Guests could include "expert reviewers" such as artists and/or scientists who could then provide additional feedback to students in a manner that echoes the collaboration of a scientific meeting. By creating a project-based environment and a "real world" context for presenting their ideas through a combination of art, writing, and oral presentation, students develop both content knowledge and useful communication skills. An "opening event" for this exhibit could even include a public performance of the kinesthetic model.

3.4.3 Telescope Activities

After students have "become" stars and nebulae, it is especially exciting to observe such objects through a telescope. If night sky access is not available, students can create their own digital images using the MicroObservatory online robotic telescopes and image processing software (see Figure 5). These experiences can be gateways to further classroom experiences with real data and astronomical observation.

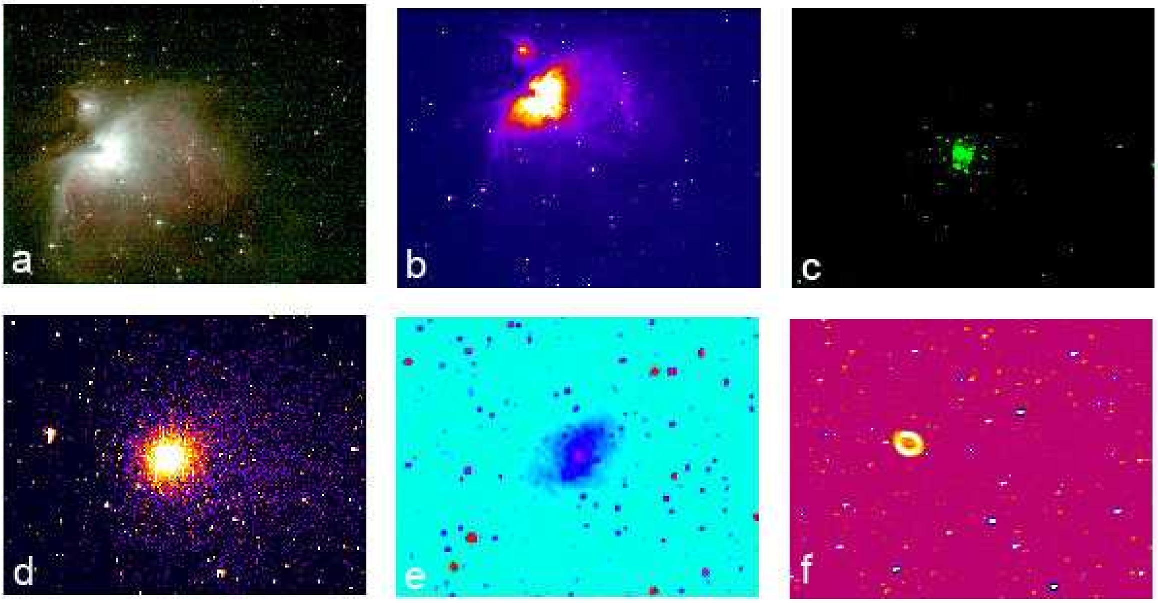

Figure 5. MicroObservatory images taken and processed by students

a) RGB image of Orion Nebula
b) False color image of Orion Nebula
c) False color image of globular cluster M15
d) False color image of globular cluster M13
e) False color image of Crab Nebula
f) False color image of Ring Nebula

Actually using a telescope to observe the universe provides incredible educational value because of the personal nature of the experience. By incorporating real data, students gain conceptual understanding of core concepts in astronomy and physical science, as well as the nature of science and inquiry (Gould, Dussault, & Sadler 2007). Relating a kinesthetic activity to actual observations is a powerful motivator for students to develop both understanding and ownership of these concepts, as well as an appreciation for what astronomers do and how science works.

4. RESULTS AND CONCLUSIONS

This activity was piloted with middle school students in after-school programs and one-day museum workshops, and with high school students in a summer research institute. Although no formal evaluation of this activity has been conducted, anecdotal evidence suggests that it is popular both with students and with out-of-school-time facilitators.

In one after-school program in downtown Boston, facilitators reported that a student who had been previously unengaged with astronomy content described the kinesthetic activity as "fun" and participated in other activities more fully after its completion. Another student who participated in this program the following year made a strong personal connection to her role as a white dwarf in the kinesthetic model when she spoke with a guest astronomer about his work studying planetary nebulae. Students in the one-day workshop made explicit references to the kinesthetic activity and to their sculptures when they processed and presented their own images of nebulae from the MicroObservatory telescopes. From this preliminary analysis, it seems that the success of this activity is primarily affective, with an emphasis on generating interest and enthusiasm for future content learning and exploration.

Recommended evaluation strategies for assessing the effectiveness of this demonstration in delivering astronomy content fall into two main categories: discussion-starting questions related to the science of the activity, and qualitative evaluation of student extension activities. In addition to establishing a metric of success for these activities, potential evaluators should also consider the quality of student questions about the content after the activity is completed, especially in comparison with those questions that arise before the activity is presented. Because this experience serves as an intermediate model for students, the development of critical thinking skills on the part of learners may be more important than any particular understanding about the life cycle of stars.

Facilitators should also be aware of potential pitfalls as they lead students through the activity. Providing too much detail about the different stages or failing to relate the narration to actual images causes students to lose focus. It is more important to debrief afterward than it is to explain every detail of every step as students are doing it. Similarly, repeat performances allow students to explore the different stages of the simulation in more depth. At first pass, some students were reluctant to participate, citing discomfort with touching their classmates or the fantasy nature of the experience. Most facilitators agreed that once students became fully immersed in the role-play, they enjoyed the experience.

When high school students were asked to create their own kinesthetic models for different stages in small groups, the results reflected students' personalities and creativity while offering facilitators the opportunity to check in with students as they researched and presented the topics at hand. However, they also required more time and student-friendly research materials. Furthermore, without communication between groups during development of the models, it was more difficult to relate each group's final interpretation of the process to the others to create a unified, coherent story. It may be possible to overcome this difficulty by discussing and agreeing beforehand how to represent the important aspects (like the balance of forces between core and envelope) or to go through one complete sequence of the student-developed models and then discuss what worked best and give each group a chance to revise. Another drawback to small-group work is, of course, the nature of teamwork; a particularly strong personality can dominate the development of a group's model, leaving other students with little chance to contribute.

Regardless of group size, students may also develop misconceptions about the model that they are creating, which should be discussed in the follow-up reflection on the activity. Extension activities can make these misconceptions visible, allowing for targeted intervention on the part of the facilitator. Facilitators should look out for the factors already discussed, including relative size and scale and the nature of specific scientific processes, as well as prior knowledge brought to the activity by students. One middle school student was already familiar with astronomical terminology and was quick to call the "planetary nebula" phase a "supernova," confusing his classmates about the differences between the deaths of high- and low-mass stars. Facilitators were able to resolve the confusion by asking students to visually compare images of the Crab Nebula and the Ring Nebula. The model will be most successful when facilitators stick to the key learning goals and emphasize them throughout the activity, as well as in extension activities.

At its core, this activity is a kinesthetic form of storytelling. The human connection to stellar evolution, be it the fate of our Sun or the origin of elements in our bodies, is a powerful story, one that is intriguing to students but difficult to visualize. It is therefore essential to explore these concepts in a hands-on way that provides concrete points of reference for future discussion and exploration. Immersing students in a dynamic, simplified model for stellar evolution makes the life cycle of stars tangible and fun.

5. ADDITIONAL RESOURCES

The resources presented in this section highlight some of the supplementary materials used by the facilitators during pilot runs of this activity. They include graphics and references for the core activity and for the extension activities described in this article. Although this list is not comprehensive, it provides a strong foundation for presenting the kinesthetic life cycle of stars in a number of different settings and programs.

Photographs of actual students engaged in the kinesthetic model:
http://www.flickr.com/photos/mkiphotos/sets/72157605963324609/

Examples of kinesthetic models developed by high school students:
http://space.mit.edu/EPO/cai/drop/kinesthetic_lifecycle_movies/

"Life Cycle of Stars" posters from NASA’s Imagine the Universe! program:
http://imagine.gsfc.nasa.gov/docs/teachers/lifecycles/stars.html

"Where Do Stars Come From? And Where Do They Go?" poster from the Hubble Space Telescope’s Amazing Space program: http://teachspacescience.org/cgi-bin/search.plex?catid=10000508&mode=full

Lithographs of "stars and stellar evolution" images from the Hubble Space Telescope:
http://amazing-space.stsci.edu/capture/stars/

Hubble Space Telescope Image Galleries:

1. Stars: http://hubblesite.org/gallery/album/star_collection/
2. Nebulae: http://hubblesite.org/gallery/album/nebula_collection/
3. News Release Archive: http://hubblesite.org/newscenter/archive/

"Stellar Cycles" card-sorting activity from the Chandra X-ray Center: http://chandra.harvard.edu/edu/formal/stellar_cycle/index.html

Kinesthetic Astronomy: http://www.spacescience.org/education/extra/kinesthetic_astronomy/index.html

MicroObservatory online robotic telescopes:

1. Telescope access: http://www.MicroObservatory.org/
2. Free image processing software: http://mo-www.harvard.edu/MicroObservatoryImage/
3. Image directory: http://mo-www.harvard.edu/jsp/servlet/MO.ID.ImageDirectory

References

Abusson, P., Fogwill, S., Barr, R., & Perkovic, L. 1997, "What Happens When Students Do Simulation-Role-Play in Science?" *Research in Science Education*, 27(4), 565.

Chabin, M. 2000, "Stellar Evolution (a la Chez Stella)," *The Universe in the Classroom*, 49, http://www.astrosociety.org/education/publications/tnl/49/chezstella.html.

Chinnici, J. P., Yue, J. W., & Torres, K. M. 2004, "Students as ‘Human Chromosomes’ in Role-Playing Mitosis & Meiosis," *The American Biology Teacher*, 66(1), 35.

Clement, J. 2000, "Model-Based Learning as a Key Research Area for Science Education," *International Journal of Science Education*, 22(9), 1041.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. 1993, *Making Sense of Secondary Science: Research into Children’s Ideas*, New York: Routledge.

Gobert, J., & Buckley, B. 2000, "Introduction to Model-Based Teaching and Learning in Science Education," *International Journal of Science Education*, 22(9), 891.

Gobert, J., Slotta, J., Pallant, A., Nagy, S., & Targum, E. 2002, "A WISE Inquiry Project for Students’ East-West Coast Collaboration," paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA, April 1-5.

Gobert, J., Snyder, J., & Houghton, C. 2002, "The Influence of Students’ Understanding of Models on Model-Based Reasoning," paper presented at the annual neeting of the American Educational Research Association, New Orleans, LA, April 1-5.

Gould, R., Dussault, M., & Sadler, P. 2007, "What’s Educational about Online Telescopes?: Evaluating 10 Years of MicroObservatory," *Astronomy Education Review*, 2(5), 127. http://aer.noao.edu/cgi-bin/article.pl?id=217.

Hufnagel, B. 1997, "Biography of a Star: Our Sun’s Birth, Life, and Death," *The Universe in the Classroom*, 39. http://www.astrosociety.org/education/publications/tnl/39/39.html.

Kirshner, R. 1994, "The Earth's Elements," *Scientific American*, 271(4), 36.

McSharry, G., & Jones, S. 2000, "Role-Play in Science Teaching and Learning," *School Science Review*, 82(298), 73.

Morrow, C. A. 2000, "Kinesthetic Astronomy: The Sky Time Lesson," *The Physics Teacher*, 38(4), 252.

Ross, P. M, Tronson, D. A., & Ritchie, R. J. 2008, "Increasing Conceptual Understanding of Glycolysis & the Krebs Cycle USING ROLE PLAY," *The American Biology Teacher*, 70(3), 163.

Sadler, P., Coyle, H., & Dussault, M. 2008, "The Astronomy and Space Science Assessment: Development and Findings," in preparation.

Wyn, M. A., & Stegnik, S. J. 2000, "Role-Playing Mitosis," *The American Biology Teacher*, 62(5), 378.